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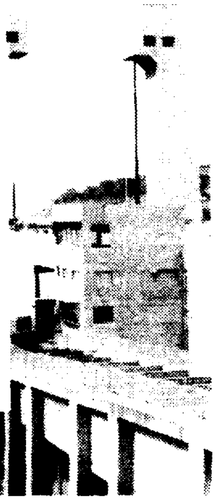
US Army Corps of Engineers



REMR RESEARCH PROGRAM

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-OM-10

LOCKWALL: A MICROCOMPUTER-BASED MAINTENANCE AND REPAIR MANAGEMENT SYSTEM FOR CONCRETE NAVIGATION LOCK MONOLITHS

by

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CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP - The vertical lift gate towers of the John Day Lock and Dam on the Columbia River.

BOTTOM - An inspector stands by a large spall inside the dewatered John Day Lock chamber

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13. ABSTRACT (Maximum 200 words)

LOCKWALL is a microcomputer-based maintenance management tool for condition assessment, condition prediction, and optimal work planning for the repair and upkeep of concrete navigation lockwalls. The development and intended use of LOCKWALL parallels that of other Engineered Management Systems developed at USACERL such as PAVER, RAILER, and ROOFER.

The concrete distress data, gathered by field inspection with a minimum of equipment, is used to calculate a Condition Index (CI) for each monolith in the data base. The CI indicates the condition of the concrete in each monolith. The CI thus affords a means for the uniform and quantitative comparison of the condition of concrete in one lock structure to that of another. The algorithm for computing the CI is described in REMR Technical Report, REMR-OM-4, *A Rating System for the Concrete in Navigation Lock Monoliths.*

In time, the collected data will yield curves showing deterioration rates of concrete in service. Such curves can be used to predict future concrete condition so that maintenance managers can optimally budget maintenance money. In addition to optimal budget planning, LOCKWALL will provide maintenance managers with justification for maintenance money and automated management reports, which will result in a better condition for dollars expended.

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PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Operations Management problem area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Unit 32280, "Development of Uniform Evaluation Procedures and Condition Index for Deteriorated Structures and Equipment," for which Dr. Anthony M. Kao is Principal Investigator. Mr. James E. Crews (CECW-OM) is the REMR Technical Monitor for this study.

Mr. Jesse A. Pfeiffer, Jr. (CERD-C) is the REMR Coordinator at the Directorate of Research and Development, HQUSACE. Mr. Crews and Dr. Tony Liu (CECW-ED) serve as the REMR Overview Committee. Mr. William F. McCleese (CEWES-SC-A), US Army Engineer Waterways Experiment Station (WES), is the REMR Program Manager. Dr. Kao is the Problem Area Leader for the Operations Management problem area.

This work was performed by the Engineering and Materials (EM) Division, US Army Construction Engineering Research Laboratory (USACERL) under the general supervision of Dr. Robert F. Quattrone, Chief of USACERL-EM. The Technical Editor was Gloria J. Wienke, Information Management Office.

Acknowledgment is due to the University of Illinois' Automation Support Center (ASC), which was contracted for the purpose of coding and compiling the LOCKWALL program.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L. R. Shaffer is Technical Director.

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PART I: INTRODUCTION

Background

1. The US Army Corps of Engineers operates approximately 270 navigation lock chambers constructed of plain or reinforced concrete. Many of these structures require, or will require, significant repairs to ensure safe and efficient operations. A quantitative rating system for the condition of concrete in navigation lock monoliths has been developed and is described in Technical Report REMR-OM-4: "A Rating System for the Concrete in Navigation Lock Monoliths" (Bullock 1989). This rating system provides a quantitative method for comparing the condition of concrete in one monolith to that in another. In time, curves showing condition versus age can be generated, thus allowing condition prediction. Such information is invaluable to maintenance managers.

2. The US Army Construction Engineering Research Laboratory (USACERL) developed a computer application that uses the rating system described in REMR-OM-4. The application, LOCKWALL, is to be used as a module in a REMR Management System for navigation lock structures. The REMR Management System will provide maintenance management tools for the miter gate, steel sheet pile, concrete monolith, operating machinery, and emptying and filling valve elements of navigation lock structures.

Objective

3. This report describes LOCKWALL, a microcomputer-based maintenance and repair management system for concrete in navigation lock monoliths. The description includes an overall view of LOCKWALL's functions and operations and a brief description of the rating system for concrete navigation lock monoliths.

Approach

4. The LOCKWALL computer application was written as a menu driven, user friendly program. LOCKWALL's fundamental features include data base management, an inventory of all lock structures within a given Division, concrete monolith condition assessment via a condition index, a collection of text files on repair and maintenance alternatives for concrete in hydraulic

structures, life cycle costs analysis (consequence modeling), and report generation. LOCKWALL is a microcomputer-based (IBM-AT or compatible) program that requires 640K RAM and a hard drive with at least 2 megabytes of free space.

Scope

5. LOCKWALL can track data for any concrete monolith within the Corps. However, LOCKWALL was written to support only one Division at a time. Accordingly, nine modules were written; one for each of the nine USACE Divisions that manage concrete navigation lock monoliths.

6. This report is not a user's manual for the LOCKWALL program. A user's manual will be published separately.

Mode of Technology Transfer

7. It is recommended that use of the LOCKWALL program be incorporated into Engineer Regulation (ER) 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures" (Headquarters, US Army Corps of Engineers 1988).

PART II: A CONDITION RATING SYSTEM

Condition Index (CI)

8. A CI is a number between 0 and 100 used to describe the condition of inservice engineering facilities. It is being used successfully on such facilities as pavements and roofs (Shahin, Bailey, and Brotherson 1987, and Shahin and Kohn 1981). The condition descriptions associated with the CI are shown in Figure 1; engineering and management actions associated with the CI are shown in Figure 2.

Benefits

9. A uniform, consistent, and quantitative method to describe the condition of concrete in lock monoliths allows maintenance managers to compare the condition of concrete in one structure to that of another. Tracking the CI as a function of time will yield curves that give the rate at which concrete in lock monoliths deteriorates. This gives managers another valuable tool; the ability to predict future condition. Quantitative knowledge of current and future condition will allow managers to create and budget optimal maintenance work plans for the structures under their supervision.

A Condition Index Rating System for Lock Monoliths

10. Such a rating system has been developed for concrete in lock monoliths (Bullock 1989). The algorithm assigns specific deduct values (DV) to each distress found in a lock monolith. The values are determined by considering the distress' extent, severity, and location. The deduct values are added and the sum is subtracted from 100 to yield a CI for each monolith. The computed CI is designed to reflect conditions and recommended actions according to Figures 1 and 2, respectively.

11. Concrete cracking and deterioration distresses addressed by the system are those defined in "Guide for Making a Condition Survey for Concrete in Service" ACI 201.1R-68 (American Concrete Institute Committee 201 1980). A "very fine" crack category was added for cracks of width 0.01 inch (0.254 mm) or less. Other distresses associated with lock monoliths, such as leaks and missing or damaged armor, are also accounted for. A listing of monolith distresses tracked by the rating system is given in Figure 3.

Value Description		Condition
85 to 100	Excellent:	No noticeable defects. Some aging or wear may be noticeable.
70 to 84	Very Good:	Only minor deterioration or defects are evident.
55 to 69	Good:	Some deterioration or defects are evident, but function is not significantly affected.
40 to 54	Fair:	Moderate deterioration. Function is still adequate.
25 to 39	Poor:	Serious deterioration in at least some portions of structure. Function is inadequate.
10 to 24	Very Poor:	Extensive deterioration. Barely functional.
1 to 9	Failed:	No longer functions. General failure or failure of a major component.

Figure 1. Condition index scale

Zone	CI Range	Action
1	70-100	Immediate action is not required.
2	40-69	Economic analysis of repair alternatives is recommended to determine appropriate maintenance action.
3	0-39	Detailed evaluation is required to determine the need for repair rehabilitation, or reconstruction.

Figure 2. General interpretation of condition index scale

CONCRETE MONOLITH DISTRESSES

CRACKING:

Diagonal
Horizontal
Longitudinal Floor
Random
Vertical & Transverse
Vertical & Longitudinal

VOLUME LOSS TYPE CRACKING/DETERIORATION:

Abrasion
Cavitation
Checking
Disintegration
D-Cracking
Honeycomb
Pattern
Pop-Outs
Scaling
Spalling

STEEL:

Exposed Prestress or Structural Steel
Exposed Reinforcing Steel

OTHER:

Corrosion Stain
Damaged Armor
Spalled Joint

LEAKAGE & DEPOSITS:

Deposits
Leakage

Figure 3. Distresses addressed by the condition index

12. The rating system uses field data obtained by visual inspection; minimal equipment is required. Inspectors use the Lock Monolith Field Inspection Form (Figures 4a and 4b). Crack widths and volume loss distresses are measured and recorded quantitatively. (Room is provided on the inspection form for sketches; however, hardware and software requirements restrict the LOCKWALL program from storing such graphical data.) The extent and severity of other distresses (e.g., corrosion stains) are recorded in a more qualitative manner; inspectors judge the extent of the distress to be heavy, medium, or light. Because some of the measurements are judgmental, the CI will vary from one inspection team to another. However, field tests show that the variation is acceptable (Bullock 1989).

A REMR Management System

13. It is important to stress that the CI calculated by this system represents only the condition of concrete in lock monoliths. The CIs are not meant to reflect overall lock structure condition. Work is planned for Fiscal Year (FY) 1990 to assemble a REMR Management System for lock structures. Condition index rating systems for steel sheet pile structures and horizontally framed miter gates have been developed (Greimann and Stecker 1990, and Greimann, Stecker, and Rens 1990). The REMR Management System for lock structures will integrate the rating systems for the steel sheet pile, horizontally framed miter gates, and concrete lockwall elements of a lock structure. Other work (developing rating systems for lock machinery and filling and emptying valves) is still in the planning stages.

LOCK MONOLITH FIELD INSPECTION FORM

Lock: ______________________________ Monolith#: _______ L M R

Date: ____________ Inspector: ____________________ Gate Block? YES NO

Location Codes
L-Land Wall M-Intermediate Wall R-River Wall
LS-Land Side Face RS-River Side Face D-Deck C-Conduit F-Floor

CRACKING

24-Horizontal 25-Vertical&Transverse 26-Vertical&Longitudinal
27-Diagonal 28-Random 29-Longitudinal Floor

1	Crack Category:	Width:	(in.)	LS	RS	D	C	F

Remarks: ______________________________

2	Crack Category:	Width:	(in.)	LS	RS	D	C	F

Remarks: ______________________________

3	Crack Category:	Width:	(in.)	LS	RS	D	C	F

Remarks: ______________________________

4	Crack Category:	Width:	(in.)	LS	RS	D	C	F

Remarks: ______________________________

VOLUME LOSS TYPE CRACKING / DETERIORATION

21-Checking 22-D-Cracking 23-Pattern 31-Abrasion 32-Cavitation
33-Honeycomb 34-Pop-Outs 35-Scaling 36-Spalling 37-Disintegration

1	Distress Category:	LS	RS	D	C	F

Distress: width _______ depth _______ height _______ elevs. __________
Section: width _______ depth _______ (at elevation of distress)
Remarks: ______________________________

2	Distress Category:	LS	RS	D	C	F

Distress: width _______ depth _______ height _______ elevs. __________
Section: width _______ depth _______ (at elevation of distress)
Remarks: ______________________________

3	Distress Category:	LS	RS	D	C	F

Distress: width _______ depth _______ height _______ elevs. __________
Section: width _______ depth _______ (at elevation of distress)
Remarks: ______________________________

Figure 4a. Front of monolith inspection form

Monolith#: ____________

Location Codes
LS-Land Side Face **RS**-River Side Face **D**-Deck **C**-Conduit **F**-Floor

STEEL

42-Reinforcing (exposed) **O**-Over 50% **U**-Under 50% **E**xposed at Section
43-Prestress (any exposure or indicated corrosion)

42 43	LS RS D C F	O U	*Remarks:*
42 43	LS RS D C F	O U	
42 43	LS RS D C F	O U	

OTHER

36-Spalled Joint **41**-Corrosion Stain **44**-Damaged Armor **LIT**-Light **HVY**-Heavy

36 41 44	LS RS	LIT HVY	*Remarks:*
36 41 44	LS RS	LIT HVY	
36 41 44	LS RS	LIT HVY	

LEAKAGE & DEPOSITS

51-Leakage **52**-Deposits **LIT**-Light **MOD**-Moderate **HVY**-Heavy
Moderate Leakage ≈ 10 gpm Moderate Deposit ≈ ½ inch thick

51 52	LS RS C	LIT MOD HVY	*Remarks:*
51 52	LS RS C	LIT MOD HVY	
51 52	LS RS C	LIT MOD HVY	

Sketches or Comments -

***-REMARKS:** In all instances describe distress locations as completely as possible. Use the the monolith's deck, faces or joints as datums. When applicable, as in volume loss, distress width and depth may be expressed as percentages of section width or depth at given elevation. For volume loss in decks, indicate the percentage of the deck area that is affected.*

Figure 4b. Back of monolith inspection form

PART III: LOCKWALL: A COMPUTER APPLICATION

14. LOCKWALL is a microcomputer-based (IBM-AT or compatible) program. It requires 640K RAM and a hard drive with at least 2 megabytes of free space. Its most important functions are to:

a. Store distress data for concrete navigation lock monoliths.

b. Calculate a CI for each monolith on which distress data exists.

c. Serve as a tool in maintenance management budgeting and planning.

Though LOCKWALL has many features, most of the features serve to support these three major functions. A brief description of each feature follows.

Data Base Administration

15. The LOCKWALL data base is comprised of a lock structures inventory, lockwall definitions, condition index inspection data, maintenance records, a text dialogue of maintenance and repair alternatives, a life cycle cost analysis, and various reports as generated by LOCKWALL. Any element of the data base can be edited or deleted with the exception of the CI itself. The CI is recalculated and stored each time the inspection data is changed. LOCKWALL maintains data at the Division level. Nine LOCKWALL modules exist; one for each of the nine Divisions managing lock structures.

16. The lock structure inventory accommodates all waterway systems and associated lock structures within a given Division. Data such as project name, location, owner, operator, lock dimensions, etc., are maintained in the inventory. New structures can be added to the data base as needed. Each of the nine LOCKWALL modules comes with a complete structural inventory in place.

17. Each structure must have its lockwalls defined in the data base. The lockwall definitions are simply lists of the numbers assigned to monoliths that comprise a given wall. For example, the upper guide wall on the land side at Mississippi River Lock & Dam #19 is comprised of monoliths 1L through 8L. The monolith numbers are taken from construction drawings. As the user prepares to enter data from a CI inspection form, the system prompts for the correct wall and the desired monolith. This process ensures that inspection teams will be using the same monolith identification numbers over time. The lockwall definitions can be edited or deleted as needed. The user must enter the wall definitions for each structure as discussed below.

Data Entry

18. The data entry portion of LOCKWALL is user friendly and menu driven where possible. Except in cases where direct numeric measurements are entered, all data is recorded by choosing responses from lists offered by the LOCKWALL program. The data entry interface was designed to emulate the Lock Monolith Field Inspection Form (Figure 4). In other words, the data is entered in the data base in the same way it was taken in the field; by filling in the necessary blanks, circling the appropriate response, and entering any remarks.

19. Before data entry can begin on any structure, the lockwall definitions must be initialized. As discussed above, this one-time process is necessary to ensure that monolith identification numbers used by different inspection teams remain consistent. Walls are defined and identification (ID) numbers obtained from construction drawings for monoliths within the wall are entered. LOCKWALL will check that every monolith within a structure is given a unique ID number. If a user tries to enter CI inspection data for a monolith that is not yet defined, LOCKWALL will signal that it does not recognize that monolith's identification number and refuse to accept data for it. For example, to enter CI data from the land side upper guide wall at L&D #19, the monolith must be numbered 1L, 2L, 3L, ..., or 8L. Though this procedure may seem bothersome, it is only necessary to do it once. The wall definitions become a permanent part of the data base.

20. Data entry begins by selecting the ADD DATA option from the main menu. LOCKWALL displays a list of all river and waterway systems within the Division and prompts the user to select the appropriate one. LOCKWALL then displays a list of all lock structures on the chosen waterway system. A structure is chosen and data entry can begin. The CI data is indexed (keyed) by structure and by inspection date.

21. After entering the inspection date (in month/year format, MM/YY) and information on the inspection team, the user selects one of the walls for the structure. After entering a monolith ID number, LOCKWALL checks to make sure that the monolith is listed in the chosen wall's definition. If so, data entry proceeds; if not, the user is instructed to double check the monolith's ID number or to edit the existing wall definition. As data entry for each monolith is completed, a CI is computed and stored. A CI report for the monolith data just entered can be brought to the screen for viewing before entering data on the next monolith. Full editorial capability in the ADD DATA path allows the user to perform "what if" tests to see what effect adding or deleting distresses will have on the CI.

22. Other data related features of LOCKWALL allow the user to view CI data, edit CI data, edit structure inventory, edit river and waterway systems,

and edit wall definitions. The sequence of first selecting the waterway then selecting the structure is the same for all the functions and options of LOCKWALL.

Reports, Forms, and Records

23. LOCKWALL generates many reports that can be tailored to the user's needs. Certain packets of information can be included or excluded from any report. Because LOCKWALL has had limited field use to date, little feedback has been received from maintenance managers regarding what they'd like the program to produce.

24. Currently, reports are classified as either Single Structure Reports or Multistructure Reports. Both categories of reports can be produced by keying on a single (or most recent) inspection date, or by keying over a range of dates. Menus allow the user to choose the information that will be included in each output.

Single Structure Reports (SSRs):

25. SSR1 lists all or any of the CI inspection data that were entered for a structure on a given date. Computed DVs and CIs for monoliths are included. As in all LOCKWALL reports, a menu allows the user to customize the output by optionally including or excluding certain packets of information (for example, a listing of the inspectors names, office symbols, and telephone numbers). An example of Single Structure Report #1 is given in Figures 5a through 5e. The report was set up to show the condition assessment for three monoliths and includes a structural inventory and monolith CI summary (Figure 5a), a listing of names, phone numbers, and office symbols of the inspection team (Figure 5b), and condition assessment listings for the three monoliths (Figures 5c, 5d, 5e).

26. SSR2 lists all or any CI inspection data that were entered for a structure for a given range of dates. Computed DVs and CIs are included. The optional output for SSR2 is the same as for SSR1, with the added feature of showing the monolith CIs plotted against time. Hypothetical graphs are shown for example in Figure 6.

27. SSR3 lists all inspection dates for any or all structures.

28. SSRWALL1 lists structure's walls, their constituent monoliths, the average CI for the monoliths within a wall, and the lowest CI for all monoliths within that wall. An example of a Single Structure Wall Report is shown in Figure 7.

29. SSRWALL2 provides the same information as SSRWALL1 but a range of dates must be specified. A graph shows the average CI and lowest CI as functions of time for each wall.

30. MAINTENANCE RECORD is a utility included in LOCKWALL to track all maintenance performed on a given structure. Figure 8 shows a blank maintenance record form. LOCKWALL allows the maintenance record to be as general or as precise as the user wishes. The user can enter as much information as desired in the fields shown. Data is entered into the data base and stored for later retrieval.

SINGLE STRUCTURE REPORT

Mississippi River
MISSISSIPPI RIVER LOCK AND DAM #19

07/29/89

Downstream City: WARSAW, ILLINOIS		
Owner: CENCR & UNION ELECT POWER CO	**State:**	**IA**
Operator: CENCR		
Completed: 1957		
Project: PN		
Number of Chambers: 1		
Length	**Width**	**Lift**
1200	**110**	**38**

Individual Monolith Condition Indices

Monolith	Condition Index
9L:LW02	89
10L:LW02	55
11L:LW02	55

Figure 5a. Structure inventory and monolith CI summary

Multistructure Reports (MSR)

31. MSR1 lists all structures within a specified river/waterway system, specified District, or Division that have monoliths with a CI at or below a specified value. Monolith numbers, distress descriptions, and condition indexes are included. The latest inspection date for each structure is used.

32. MSRWALL1 lists all structures within a specified group of structures that have walls with an average CI at or below a specified value.

Inspection Team

Name:	Fred Joers	(309)-788-6361
Office:	CENCR-ED-DS	
Title:	Structural Engineer	
Name:	Wen Tsau	
Office:	CENCR-ED-DS	
Title:	Structural Engineer	(309)-788-6361
Name:	Dave McKay	
Office:	CECER-EM	
Title:	Civil Engineer	(217)-373-7241
Name:	Tony Kao	
Office:	CECER-EM	
Title:	Civil Engineer, P.E.	(217)-373-7238
Name:	Jim Stecker	
Office:	CECER-EM, IPA	
Title:	Civil Engineer	(515)-232-4638

MISSISSIPPI RIVER LOCK AND DAM #19

Figure 5b. Inspection team listing

SINGLE STRUCTURE REPORT #1: MISSISSIPPI RIVER LOCK AND DAM #19 (NCR)

Monolith #9L:LW02 Gate Block? YES Land Wall

CRACKING	LOCATION	WIDTH		DV
No cracking distress for this monolith.				

VOLUMETRIC CRACKING	LOCATION	%WIDTH	%DEPTH	DV
Abrasion	River Side	100.0 %	0.56 %	3
Comments: 4' tall, along top of wall				

EXPOSED STEEL	LOCATION	AMOUNT	DV
None for this monolith.			

CONDUITS	DEPTH	DV
No conduit distress for this monolith.		

OTHER	LOCATION	AMOUNT	DV
None for this monolith.			

LEAKAGE & DEPOSITS	LOCATION	AMOUNT	DV
No leakage or deposit distress for this monolith.			

DECKS	AMOUNT	DV
D-Cracking	Under 25 %	5
Comments: very light, at corners		

GATE BLOCK DEDUCT = 3

TOTAL DEDUCT = 11

CONDITION INDEX = 89

KEY: * - This distress ignored in C.I. calculation.
+ - These distresses add to a maximum deduct of 20.
? - This distress has missing data.
Rn - Distresses tagged with Rn are related, and are treated as a single distress with a single D.V.

Inspection Date: 04/89 Monolith #9L:LW02.1 Report: 29-JUL-1989

Figure 5c. Condition assessment listing for monolith #9L

SINGLE STRUCTURE REPORT #1: MISSISSIPPI RIVER LOCK AND DAM #19 (NCR)

Monolith #10L:LW02 Gate Block? NO Land Wall

CRACKING	LOCATION	WIDTH	DV

No cracking distress for this monolith.

VOLUMETRIC CRACKING	LOCATION	%WIDTH	%DEPTH	DV
Honeycomb	River Side	6.67 %	1.67 %	*

Comments: 28' below deck, shows exposed re-bars, el 500', 36"x8"x5"

EXPOSED STEEL	LOCATION	AMOUNT	DV
Reinforc.	River Side	Under 50%	30

CONDUITS	DEPTH	DV

No conduit distress for this monolith.

OTHER	LOCATION	AMOUNT	DV
Spalled Joint	River Side	Light	5 +

Comments: upstream joint, 10' below deck, 2'x2'x1'

LEAKAGE & DEPOSITS	LOCATION	AMOUNT	DV
Leakage	River Side	Light	5 +

Comments: water leaks at spalled joint

DECKS	AMOUNT	DV
Pattern	Under 25 %	5

TOTAL DEDUCT = 45

CONDITION INDEX = 55

KEY: * - This distress ignored in C.I. calculation.
+ - These distresses add to a maximum deduct of 20.
? - This distress has missing data.
Rn - Distresses tagged with Rn are related, and are treated as a single distress with a single D.V.

Inspection Date: 04/89 Monolith #10L:LW02.1 Report: 29-JUL-1989

Figure 5d. Condition assessment listing for monolith #10L

SINGLE STRUCTURE REPORT #1: MISSISSIPPI RIVER LOCK AND DAM #19 (NCR)

Monolith #11L:LW02 Gate Block? NO Land Wall

CRACKING	LOCATION	WIDTH		DV
Vert. & Long.	Deck	0.030 IN		30
Comments: runs from bulkhead slot to floating mooring bit guide				

VOLUMETRIC CRACKING	LOCATION	%WIDTH	%DEPTH	DV
No volumetric cracking distress for this monolith.				

EXPOSED STEEL	LOCATION	AMOUNT	DV
None for this monolith.			

CONDUITS	DEPTH	DV
No conduit distress for this monolith.		

OTHER	LOCATION	AMOUNT	DV
Spalled Joint	River Side	Light	5 +
Comments: either end at low pool			

LEAKAGE & DEPOSITS	LOCATION	AMOUNT	DV
No leakage or deposit distress for this monolith.			

DECKS	AMOUNT	DV
Pattern	Over 25 %	10
Comments: very fine		

TOTAL DEDUCT = 45

CONDITION INDEX = 55

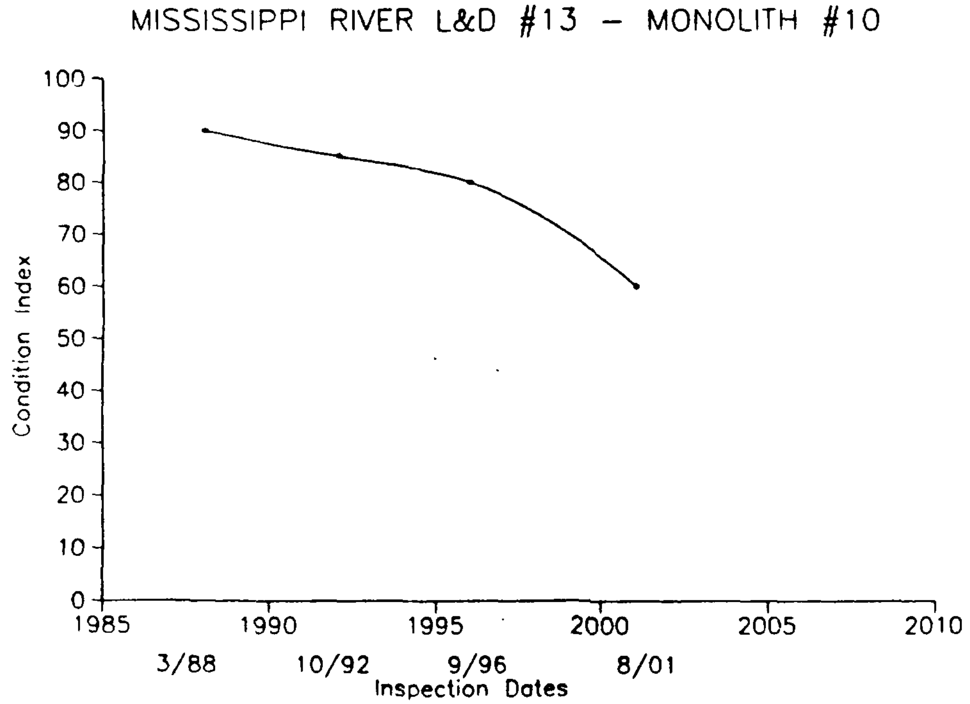
KEY: * - This distress ignored in C.I. calculation.
+ - These distresses add to a maximum deduct of 20.
? - This distress has missing data.
Rn - Distresses tagged with Rn are related, and are treated as a single distress with a single D.V.

Inspection Date: 04/89 Monolith #11L:LW02.1 Report: 29-JUL-1989

Figure 5e. Condition assessment listing for monolith #11L

SINGLE STRUCTURE REPORT #2

October 10, 2001



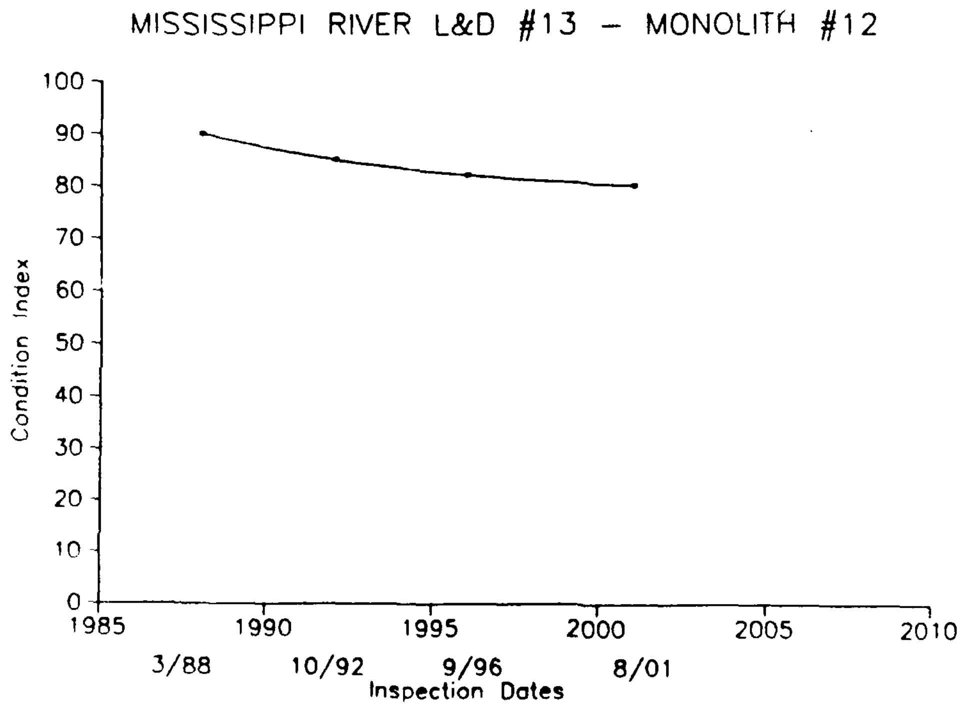


Figure 6. Monolith CI vs time

33. MSRWALL2 is a simple listing of wall descriptions (wall name and constituent monoliths) for all or any group of specified structures.

34. Other output produced by the LOCKWALL program that do not fall into either the single structure or multistructure formats are the lock monolith field inspection form (Figure 4), a lock monolith CI calculation form (Figure 9), and hard copy of all Maintenance and Repair Alternatives files as discussed in the next section.

Maintenance and Repair Alternatives Files

35. A wealth of information regarding maintenance and repair operations for concrete lockwalls has been gathered and stored in the LOCKWALL program. The information exists in the form of American Standard Code for Information Interchange (ASCII) files. These ASCII files can be sent to the microcomputer monitor for viewing or to the printer for hard copy. The primary sources of information contained in these files were ACI Manual of Concrete Practice Parts I-V 1987; Bullock 1989; Headquarters, US Army Corps of Engineers 1986; and McDonald 1987. Much of the text from these references is repeated directly by the LOCKWALL program.

Mississippi River Lock & Dam #19, Keokuk, IA

Inspected: APRIL 1989

WALL DESCRIPTION	MONOLITH #S	CI AVG	CI LOW
Upper Guide Wall (LS)	1L - 8L	85	85
Main Chamber Wall (LS)	9L - 49L	76	50
Lower Guide Wall (LS)	50L - 67L	93	85
Upper Guide Wall (RS)	1R	90	90
Main Chamber Wall (RS)	2R - 41R	87	55
Lower Guide Wall (RS)	42R - 51R	80	70

* LS - Land Side, RS - River Side

Figure 7. SSRWALL1

36. The files are sorted into three groups: TERMS & DEFINITIONS, SYMPTOMS & CAUSES OF DISTRESS, and REHABILITATION TECHNIQUES & ALTERNATIVES. The files serve as a library to help the user research and determine proper maintenance strategies for a given set of distresses.

MAINTENANCE RECORD

ACTIVITY TITLE: ____________________

DATE: __________ **IN HOUSE / CONTRACT (I/C):** ______

CONTRACT NO.: __________

TOTAL COST: $ __________

LABOR COST: $ __________ **MATERIAL COST: $** __________

IN HOUSE LABOR HOURS:

1) **CREW TYPE:** __________ **MAN HOURS:** ______

2) **CREW TYPE:** __________ **MAN HOURS:** ______

3) **CREW TYPE:** __________ **MAN HOURS:** ______

4) **CREW TYPE:** __________ **MAN HOURS:** ______

5) **CREW TYPE:** __________ **MAN HOURS:** ______

PROBLEM DESCRIPTION: ____________________

ACTIVITY DESCRIPTION: ____________________

Figure 8. Maintenance record

LOCK MONOLITH CONDITION INDEX CALCULATION FORM

Lock: ______________________________ Monolith#: __________

Date: __________ Inspector: ________________ Gate Block? yes no

Alignment Problems?: ______________________________

DISTRESS CATEGORIES:

	DIVISION A: All Blocks				DIVISION B: Gate Block			
	Deduct Values				Additional Deducts			
CRACKING	<=.01"	<=.04"	<=.08"	>.08	<=.01"	<=.04"	<=.08"	>.08
24 Horizontal	10	20	30	40	5	10	15	20
25 Vert & Transverse	10	20	30	40	-	10	20	30
26 Vert & Longitudinal	10	30	50	70	-	-	-	-
27 Diagonal	20	40	60	80	-	-	-	-
28 Random	10	20	40	60	-	-	-	-
29 Longit Floor	10	20	30	40	5	10	15	20

VOLUMETRIC CRACKING	%Width	%Depth	Deduct
21 Checking	100	10	50
22 D-Cracking	100	6	30
23 Pattern	100	2	10
	50	10	25
VOLUME LOSS	50	6	15
31 Abrasion	50	2	5
33 Honeycomb	20	10	10
34 Pop-outs	20	6	6
35 Scaling	20	2	2
36 Spalling	Other:		
37 Disintegration	%Width	%Depth	Deduct
Deduct = (%W)*(%D)/20	_____	_____	_____

STEEL	Any Area	> 50% Area
42 Reinforcing (exposed)	30	60
43 Prestress (corrosion)	60	

CONDUITS	<= 3"	<= 6"	> 6"
31 Abrasion	10	20	30
32 Cavitation	20	40	60

Enter MAX Div. A:_____

DIVISION B: Additional Deduct

The additional deduct value for volume loss type distress in gate blocks is equal to the deduct value computed in Division A.

Enter Deduct:_____

Enter MAX Div. B:_____

DIVISION D: Decks

Categ	<25% Area	>25%
_____	5	10
_____	5	10
_____	5	10

Enter SUM Div. D:_____

DIVISION C

OTHER	Deduct Values Light		Heavy
36 Spalled Joint	5		10
41 Corrosion Stains	5		10
44 Damaged Armor	5		10
LEAKAGE & DEPOSITS	Light	Moderate	Heavy
51 Leakage	5	10	20
52 Deposits	5	10	20

Sum Div C:_____<20 MAX

COMPUTE DEDUCT VALUE:

1) Max Div. A = _____
2) Max Div. B = _____
3) Sum Div. C = _____
4) Sum Div. D = _____

TOTAL DEDUCT = _____

C. I. RATING = _____

Figure 9. Lock monolith CI calculation form

37. TERMS & DEFINITIONS is a collection of files that provides definitions of distress and other terms commonly associated with concrete, and maintenance and repair of concrete structures. Specific distresses are addressed and a glossary of concrete terminology is supplied.

38. DISTRESS - SYMPTOMS & CAUSES. Before deciding on the repair procedure for distress in concrete, the cause of the distress must first be determined. This group of files leads the user through the process of correctly relating distress symptoms to the actual cause of the distress. The files include information on accidental loadings, chemical reactions, construction errors, corrosion of embedded metals, design errors, erosion, freezing and thawing, settlement and movement, shrinkage, temperature changes, and weathering.

39. LOCKWALL REHABILITATION - TECHNIQUES & ALTERNATIVES. Once the cause of the distress is identified, a repair plan can be formulated. A decisionmaking process is identified and discussed. The process takes into account the distress type and cause and, through a decision tree, narrows down the number of feasible repair alternatives.

40. The files collected in this section discuss in detail such subjects as concrete removal and preparation for repair, proper selection of materials according to specific distress types, and proper selection of repair methods. Repair methods discussed include conventional concrete placement, epoxy injections, grouting, overlays, precast stay-in-place forming, preplaced aggregate concrete, routing and sealing, shotcrete, and stitching. Other topics include concrete maintenance, surface coatings, joint maintenance, and water stop failures.

41. The files do not interact with the CI data base in any way. They are in place strictly for informational purposes.

Life Cycle Cost Analysis

42. The LOCKWALL program has a Life Cycle Cost Analysis (LCCA) utility that can be tied directly to the CI inspection data base. In terms of LCCA maintenance planning, all LCCAs require a standard input: current inflation rate, current interest rate, required life of overall maintenance plan, beginning year of maintenance plan, individual maintenance activity description, current cost of individual maintenance activity, expected life of individual maintenance activity, and beginning year of individual maintenance activity. The standard output is a financial schedule showing the required real-time dollars and present worth of such dollars to implement each individual maintenance activity. Total cost and total present worth for the overall plan are presented.

43. The LCCA utility in LOCKWALL is unique in that it is possible to perform LCCA analyses directly on distresses contained in the data base. Maintenance plans can be entered for each monolith or, if desired, for any group of monoliths. A complete listing of the monoliths and their distresses and deduct values are presented to the user. As maintenance activities are entered for each distress, new condition indexes are calculated. It is assumed that performing a repair on a distress will bring the deduct value for that distress to zero. LOCKWALL produces the standard LCCA output as described above, but also includes a listing of the CIs for each monolith as prescribed maintenance activities are completed.

44. This LCCA utility thus allows managers to create many different maintenance plans. The plans can be manipulated to achieve a desired CI for any monolith at any given time. If preferred, the LCCA can be used without linking to the data base. General maintenance plans, without reference to individual monoliths, can be prepared but CI information cannot be produced with the output.

45. Figures 10a through 10c provide a simple example of how the LCCA utility works. For this example, a maintenance plan for monoliths 9L, 10L, and 11L at Mississippi River L&D #19 is presented. After entering interest and inflation rates, the beginning year, and total life of the maintenance plan, the user is shown a template and asked to fill in the blanks (see Figure 10a). For each distress shown on the template, the user enters a maintenance activity description, cost of the activity, expected life of the activity, and the year the activity is to be applied. Figure 10b shows the completed template before calculation. Deduct values are set to zero if maintenance is performed. Figure 10c shows the resulting required dollars and present worth of such dollars to realize the proposed maintenance plan.

CREATE A NEW LIFE CYCLE COST ANALYSIS

Monolith Number	Distress	M&R Alternative	Cost	Rep. Life	Str. Year	Deducts Old	Deducts New
9L:LW02	D-Cracking		0	0		5	5
9L:LW02	Abrasion		0	0		3	3
10L:LW02	Honeycomb		0	0		1	1
10L:LW02	Pattern		0	0		5	5
10L:LW02	Reinforc.		0	0		30	30
10L:LW02	Spalled Joint		0	0		5	5
10L:LW02	Leakage		0	0		5	5
11L:LW02	Vert. & Long.		0	0		30	30
11L:LW02	Pattern		0	0		10	10
11L:LW02	Spalled Joint		0	0		5	5

F1:Help F2:Delete F3:Calc F5:Re-Select F6:Defaults F10:Done

Figure 10a. Blank LCCA template

CREATE A NEW LIFE CYCLE COST ANALYSIS

Monolith Number	Distress	M&R Alternative	Cost	Rep. Life	Str. Year	Deducts Old	Deducts New
9L:LW02	D-Cracking	Repair Deck 9L	5000	10	1995	5	0
9L:LW02	Abrasion		0	0		3	3
10L:LW02	Honeycomb	Patch Honeycomb 10L	20000	25	1990	1	0
10L:LW02	Pattern	Repair Deck 10L	5000	10	1995	5	0
10L:LW02	Reinforc.	10L Honeycomb Patch	0	0		30	0
10L:LW02	Spalled Joint	9L 10L Spalled Joint	10000	25	1990	5	0
10L:LW02	Leakage	9L 10L Spalled Joint	0	0		5	0
11L:LW02	Vert. & Long.	Stitch V&T crack 11L	12000	10	1990	30	0
11L:LW02	Pattern	Repair Deck 11L	5000	10	1995	10	0
11L:LW02	Spalled Joint		0	0		5	5

F1:Help F2:Delete F3:Calc F5:Re-Select F6:Defaults F10:Done

Figure 10b. LCCA template ready for calculation

SAMPLE LIFE CYCLE COST ANALYSIS

River: Mississippi River — Report Date: 07/29/89
Structure: MISSISSIPPI RIVER LOCK AND DAM #19 — Insp. Date: 04/89
Life of Alternative = 25 — Interest Rate = 10.00 — Inflation Rate = 5.00

M & R ACTIVITY	YEAR	COST(S)	PRESENT VALUE
Patch Honeycomb 10L	1990	$ 20,000	$ 20,000
9L 10L Spalled Joint	1990	10,000	10,000
Stitch V & T crack 11L	1990	12,000	12,000
** Subtotals for YEAR 1990		42,000	42,000
Repair Deck 9L	1995	5,000	3,962
Repair Deck 10L	1995	5,000	3,962
Repair Deck 11L	1995	5,000	3,962
** Subtotals for YEAR 1995		15,000	11,886
Stitch V & T crack 11L	2000	12,000	7,536
** Subtotals for YEAR 2000		12,000	7,536
Repair Deck 9L	2005	5,000	2,488
Repair Deck 10L	2005	5,000	2,488
Repair Deck 11L	2005	5,000	2,488
** Subtotals for YEAR 2005		15,000	7,464
Stitch V & T crack 11L	2010	12,000	4,733
** Subtotals for YEAR 2010		12,000	4,733
Repair Deck 9L	2015	5,000	1,563
Patch Honeycomb 10L	2015	20,000	6,251
Repair Deck 10L	2015	5,000	1,563
9L 10L Spalled Joint	2015	10,000	3,125
Repair Deck 11L	2015	5,000	1,563
** Subtotals for YEAR 2015		45,000	14,065
Report totals:		141,000	87,684

Figure 10c. LCCA output: required dollars and present worth

PART IV: CONCLUSIONS AND RECOMMENDATIONS

46. LOCKWALL as it exists now is in an infant stage. It has had limited exposure in the field and will certainly change as user feedback becomes available. Some features of LOCKWALL are now ready for further development to bring it to a more mature and powerful maintenance management tool.

47. One of LOCKWALL's primary functions is to track the condition of concrete in navigation lock monoliths. In doing so, LOCKWALL produces data indicating concrete condition as a function of time. Curves plotted from this data can be used to predict future concrete condition (assuming normal deterioration and no repair); but these curves could take years to produce a complete life cycle. Using LOCKWALL's CI inspection data base, statistical methods can be applied to concrete with similar characteristics (age, environment, chemical parameters, etc.), to produce life cycle/condition deterioration curves. A statistically reliable condition prediction model is needed.

48. An improved method for using monolith CIs to represent overall lockwall condition should be investigated. The current method of reporting the average and lowest monolith CI for each wall is crude at best. Initial steps have been taken in this area (Markow 1989), but results have not been completely evaluated.

49. It may be possible to connect the CI inspection data base with a maintenance and repair alternatives knowledge base. This connection can yield an automated procedure that generates maintenance plans. At the least, an interface can be installed where, by asking or answering the right questions, a select field of feasible maintenance alternatives can be identified automatically. It may also be possible to implement an economic factors data base that can associate unit costs with any type of selected repair alternative.

50. LOCKWALL underwent initial field testing during April and May 1989. CI inspections were performed at six sites in three districts (Nashville, Rock Island, Tulsa). CI inspection data were entered into LOCKWALL and condition assessment reports for the monoliths were printed. Upon completion of testing, all personnel involved in performing the inspections and evaluating the resulting CIs gathered to compare field experiences and test results. The inspection procedure proved simple, the data processing straightforward, and the condition assessment of the concrete was deemed accurate. In the few cases where there was disagreement with the condition assessment, the CI was deemed to be too low in each case. Refinements and enhancements were suggested for both the CI inspection procedure and the CI calculation algorithm.

51. As LOCKWALL gets more field exposure, comments and suggestions will be considered for incorporation into the program. Program changes will be made to resolve problems with the inspection procedures. As maintenance

managers become used to using the system, the report formats can be tailored to their needs. To date, LOCKWALL, the CI, and the concept of an automated maintenance management system have received enthusiastic support.

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